

# **Modeling the ecosystem services provided by trees in urban ecosystems: using Biome-BGC to improve i-Tree Eco**

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## **Abstract**

As the world becomes increasingly urban, the need to quantify the effect of trees in urban environments on energy usage, air pollution, local climate and nutrient run-off has increased. By identifying, quantifying and valuing the ecological activity that provides services in urban areas, stronger policies and improved quality of life for urban residents can be obtained. Here we focus on two radically different models that can be used to characterize urban forests. The i-Tree Eco model (formerly UFORE model) quantifies ecosystem services (e.g., air pollution removal, carbon storage) and values derived from urban trees based on field measurements of trees and local ancillary data sets. Biome-BGC (Biome BioGeoChemistry) is used to simulate the fluxes and storage of carbon, water, and nitrogen in natural environments. This paper compares i-Tree Eco's methods to those of Biome-BGC, which estimates the fluxes and storage of energy, carbon, water and nitrogen for vegetation and soil components of the ecosystem. We describe the two models and their differences in the way they calculate similar properties, with a focus on carbon and nitrogen. Finally, we discuss the implications of further integration of these two communities for land managers such as those in Maryland.

## **1.0 Introduction**

Trees in the urban environment provide significant ecosystem services to urban residents. Researchers have sought to define these benefits in the context of a broader effort to understand how urban environments function in relationship with natural ecosystems (Costanza et al. 1997). By identifying, quantifying and valuing the ecological activity that provides services in urban areas, stronger policies and improved quality of life for urban residents can be obtained. In this paper we are concerned with urban trees, which provide a wide range of services and amenities to the urban environment (Nowak and Dwyer 2007). Urban trees and forest patches contribute to air filtering, micro-climate regulation, noise reduction, rainwater runoff reductions, and improved recreation/cultural values (Bolund and Hunhammar 1999).

Accurate and quantitative maps of urban forests have been long been sought as an important part of an urban tree management strategy. Knowledge of the urban forest, specifying where the trees are, what species are represented, how old and healthy they are and determining their distribution geographically has great value for planners, city foresters, ecologists, landscape architects, tree advocacy groups, and urban residents (Saxe et al. 2001). Information about how urban trees are changing and how they contribute to local climate mitigation and adaptation goals has recently emerged as an important theme with trees included in regional climate models in large urban areas to estimate their contribution to reductions in the urban heat island . (Cynthia Rosenzweig 2009)

Recent federal legislation, such as the Energy Policy Act of 2005 (109<sup>th</sup> Congress, 2005) and Executive Order 13514 emphasizes the necessity to quantify the effects of

environmental protection measures and climate change adaptation programs, especially on federal facilities. In addition, there is a movement for voluntary and state mandate climate action plans for cities that include greenhouse emission accounting and mitigation.

However, the complexity of ecosystems leads to difficulty in conducting such studies. The fields of forestry, agriculture, urban planning and environmental engineering must come together to create a useful tool that can model the interactions between plants and the built environment. Fortunately, several models already exist that model and quantify energy, water fluxes, and carbon sequestration within different types of ecosystems.

The goal of this research is to provide examples of how elements of two different environmental models can improve the other's ability to enable estimation of ecosystem services, health benefits, and carbon sequestration information on existing and future forest resources on private, municipal, county, state and federal facilities. In this paper, we present how a nitrogen uptake algorithm from an ecosystem process model (Biome-BGC) was incorporated into i-Tree Eco (formerly Urban Forest Effects (UFORE) model), an urban forest assessment model. i-Tree Eco calculates the structure, environmental effects and values of urban forests through ground sampling and site-specific calculations. Through this illustrative example, we provide concrete evidence of the benefits of bridging different forest modeling approaches and modeling communities.

## **1.1 Forest Models and Ecosystem Services**

Scientists have developed biophysical process models to understand the function of forests, particularly to explicitly represent the complex interplay between the local environment and each individual in the community (Deutschman et al. 1997). Urban forests, however, are often excluded from many ecosystem models, as most aim to

understand the interactions present in a natural forest environment and are often implemented at a spatial resolution not useful in diverse and complex urban environments. The need for models that incorporate explicit species information combined with information on changes through time and of carbon stocks is growing as more cities adopt policies that promote trees as ways to augment ecosystem services in the region (McPherson et al. 2005, Peters et al. 2010). The impact of changing atmospheric chemistry and temperatures on trees will become increasingly important in the efforts of forest managers to estimate stock replacement and management strategies.

As urban and suburban areas grow, the area that needs to be excluded from process models designed for use in natural ecosystems becomes larger. In the Chesapeake Bay watershed, for example, the total amount of urban area in the Bay watershed increased by 14 percent, or 355,146 acres, between 1984 and 2006. Tree canopy decreased from 62.6 percent of the watershed in 1984 to 61.5 percent in 2006, a loss of 439,080 acres (Claggett 2010). In addition, urban land is projected to increase from 3.1 to 8.1 percent of the conterminous United States between 2000 and 2050 given urban growth patterns of the 1990s (Nowak and Walton 2005). Tree cover in urban areas are also a significant resources covering 35.0 percent of urban areas in the United States (Nowak and Greenfield 2012). Forests in this region are fragments managed by private, federal and state entities that have limited resources but extensive mandates to prevent forest loss. Tree species in these urban and suburban environments are often exotic and of varying age. At the landscape and regional scales, species composition is an important factor controlling the magnitude and seasonality of evapotranspiration, growth of biomass and carbon sequestration (Fan et al. 1998, Goetz and Prince 1998).

## **1.2 Study Site: University of Maryland College Park**

The study site for this analysis is the University of Maryland College Park (UMCP), in Prince George's County, Maryland. The University's Facilities Master Plan 2001-2020 stipulates preservation and reinforcement of regional ecological connections and recommends establishing greenways; managing invasive species; protecting streams, wetlands; protecting existing specimen trees; and restoring and enhancing forest cover. This plan requires extensive and comprehensive information on forest species, the growth of the trees through time, and an estimation of mortality rate. Because of these efforts, UMCP forest managers have conducted two tree surveys in the past decade to provide input into the i-Tree Eco model. The model results quantify the benefits of campus trees.

## **2.0 UFORE and Biome-BGC**

Both the Biome-BGC and i-Tree Eco models were applied to our study site of the University of Maryland College Park campus.

### **2.1 Model background on i-Tree Eco**

The i-Tree Eco model was originally developed as the Urban Forest Effects (UFORE) model by the US Forest Service Northern Research Station in the mid- to late 1990s. This model estimates ecosystem services and values provided by urban trees and has been incorporated within a suite of urban forest models called i-Tree ([www.itreetools.org](http://www.itreetools.org)), which is free software developed and supported by the US Forest Service and several partners. i-Tree incorporates local vegetation data and local hourly meteorological and pollution-concentration measurements to quantify location-specific information about

vegetation structure and associated ecosystem services over a one-year period. The model currently estimates: 1) forest structural attributes such as number of trees, species composition, tree density, tree health, leaf area, leaf biomass, 2) hourly volatile organic compound emissions from trees, 3) carbon storage and annual carbon sequestration by trees, 4) hourly air pollution removal by trees (ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide, and particulate matter less than 10 microns), and 5) tree effects on annual building energy use (Nowak et al. 2008). The first step in conducting an i-Tree Eco assessment is to determine the purpose of the study, as the purpose determines the number of tree attributes required and area to be sampled, and therefore the project's costs. Once objectives are determined, tree data are measured within randomly located sample plots throughout the study area to provide the base tree information for the model (Nowak, Hoehn, Crane, Stevens, Walton and Bond 2008).

Field data collection within plots includes land use, ground and tree cover, shrub characteristics, as well as individual-tree attributes of species, stem diameter at breast height (1.37 m), tree height, height to base of live crown, crown width, percent crown dieback, and distance and direction from buildings (Nowak et al. 2008). Field data are entered into the i-Tree Eco program and processed based on a server-based application that incorporates local hourly weather (derived from National Climatic Data Center data) and pollution data (derived from U.S. Environmental Protection Agency monitors). Model outputs include standard tables, graphs and a report, all of which can be exported and customized.

i-Tree Eco methods can be applied to areas of any size and to non-urban areas. Model

results have been cross-checked and verified against test data sets and field measurements. The model also translates ecological measurements such as kilograms of carbon sequestered per year into estimated economic savings, helping to link model information to the scientific and policy-making communities (Nowak, Hoehn, Crane, Stevens, Walton and Bond 2008).

The i-Tree results from the 2008 analysis were derived from data from 101 field plots located throughout University of Maryland (Keen et al. 2010).

Key findings for the UMCP campus were:

- Number of trees: 166,000
- Tree cover: 29.2%
- Most common species: red maple (14.3 percent), sweetgum (10.4 percent), black tupelo (10.3 percent).
- Percentage of trees less than 6" (15.2 cm) diameter: 67.5%
- Pollution removal: 17 metric tons/year<sup>1</sup> (\$91.3 thousand/year in 2008 dollars)
- Carbon storage<sup>2</sup>: 22,400 metric tons (\$510 thousand)
- Carbon sequestration<sup>3</sup>: 683 metric tons/year (\$15.6 thousand/year)
- Building energy savings: \$87.7 thousand / year
- Avoided carbon emissions: \$3,530 / year
- Structural values<sup>4</sup>: \$81.5 million

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<sup>1</sup> Metric ton: 1000 kilograms

<sup>2</sup> Carbon storage: the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation

<sup>3</sup> Carbon sequestration: the removal of carbon dioxide from the air by plants through photosynthesis

<sup>4</sup> Structural value: value based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree)

## **2.2 Model background on Biome-BGC**

Biome-BGC is used primarily by ecosystem scientists to model the flows of carbon, nitrogen, and water in various ecosystems (White et al. 2000). Biome-BGC has been used to study carbon sequestration, the hydrologic cycle, and the effects of disturbances such as forest fires in various natural ecosystems (White et al. 2002). Biome-BGC outputs quantify carbon, nitrogen and water fluxes in a study area over time. Outputs are in carbon, nitrogen or water mass per area per day, and interpretation of results is left up to the scientists conducting the study. One of the strengths of the model is its simulation modeling capabilities. Researchers can experiment with Biome-BGC by changing its inputs and mathematical parameters and critically examining the changes in simulated ecosystem development that accompany their manipulations (Milesi et al. 2003). Biome-BGC is poorly suited to accommodate urban or other human-developed land covers, so it is primarily used in studies of natural ecosystems.

Biome-BGC is a simulation process-model that uses general vegetation and soil parameters in conjunction with meteorological data and land characteristics to estimate daily fluxes and states of carbon, water, and nitrogen within an ecosystem (Running and Coughlin 1988, Running and Gower. 1991, Running and Hunt 1993). Biome-BGC is a point model that can be run as a grid model if continuous data layers are available.

When run as a grid model, Biome-BGC's calculations do not take into account interactions between cells. Depending on type of vegetation, land topographical characteristics, soil characteristics, and meteorological data, Biome-BGC simulates the development of plant biomass in an ecosystem at a daily time step. On each simulated day,



Biome-BGC simulates the transfer passes a certain amount of carbon, nitrogen, and water between different atmospheric, soil, and biomass pools. The amount of nutrient moved between the pools is based on meteorological data and process models of the carbon cycle, nitrogen cycle, and hydrologic cycle specific to the biome type being simulated.

Vegetation cover is classified according to one of seven general biomes. The forested biomes are broken into four subcategories based on leaf type and phenology: evergreen needle leaf and broadleaf, deciduous needle leaf and broadleaf. The grass biomes are divided into two distinct types of grasses depending on the species' photosynthesis process. A shrub biome type is also supported by Biome-BGC. Each of the seven biome types is simulated using a complete set of ecophysiological parameters which were determined through compilation of a broad literature survey quantifying allocation parameters and characteristics of nutrient cycles within different species (White et al., 2000) (Figure 1). The user has a choice to use either the average values compiled for a given biome or to use ecophysiological parameters characteristic of an individual species or species composition. Biome-BGC does not explicitly support a biome representing biomass or other abiotic or biotic climate processes in urban areas but can be adapted to simulate processes in urban ecosystems through appropriate parameterization (Milesi et al. 2005).

The first step to conducting a Biome-BGC study is determining a study area and gathering initialization parameters such as biome type, land topographic information, and soil characteristics. These parameters can be interpreted from previously mapped data, field studies of the study area, or field studies of similar areas. When the initialization

parameters have been collected, historical daily meteorological data including maximum and minimum temperature, precipitation, and solar radiation must also be supplied. Spinup simulations are required to bring the amount of carbon stored in the soils in equilibrium with the local climate.

In this study we implemented Biome-BGC over the University of Maryland's College Park campus (Latitude 38.996, Longitude -76.934). We ran the Biome-BGC version 4.2 program for a thirty-year time period, from 1978 to 2008, with 6000 years of spin-up and based on climate data from College Park derived from Daymet (Thornton et al. 1997, Kimball et al. 1997). The results in Figure 2 shows the annual net biome production (NBP) on the University of Maryland site, denoting the amount of carbon that remains at the site after subtracting respiratory and non-respiratory (e.g. fires) losses. Although NBP is considered an appropriate concept for analyzing long-term and large-scale changes to the carbon cycle through changes in land use, it may not be directly comparable to carbon calculations from i-Tree Eco.

### **2.3 Comparing i-Tree Eco and Biome-BGC**

i-Tree Eco and Biome-BGC are different in their intended applications, intended users, model theory, and program structure, but these differences are potential strengths waiting to be fully developed. i-Tree Eco, an urban forest model, is intuitively targeted towards landscape managers and policymakers who need to understand the wider effects of the landscaping decisions made in their areas of interest. Biome-BGC, a comprehensive ecosystem model, simulates the study area's development through time, but assumes a natural, non-urban ecosystem and does not interpret its outputs beyond specific mass

flows of water and carbon. Each distinct attribute can be conceivably integrated into the opposite model for a stronger and more versatile modeling framework. Table 1 lists key strengths and weaknesses of these two programs for the urban manager.

### **3.0 Estimating nitrogen uptake in urban forests**

In temperate ecosystems nitrogen (N) is a commonly considered the primary limitation on primary productivity (Vitousek and Howarth 1991). In Biome-BGC, availability of nitrogen determines the amount of carbon sequestered by the vegetation. Human activities have increased N inputs into a number of previously N-limited ecosystems (Vitousek et al 1998). While increased N inputs have alleviated N limitation, they have also led to significant ecological problems resulting from the leaching of excess N to adjacent waterways, as well as loss of essential base cations from soils, increased production of N-based greenhouse gases and shifts in community composition leading to decreased diversity (Vitousek et al. 1997). Trees and forests in urban areas are particularly vulnerable to wet air deposition of nitrogen. The adverse environmental and ecological effects of N pollution result from the contributions of nitrogen in four major areas: (1) acidic deposition, ground-level ozone (O<sub>3</sub>) formation, and visibility loss; (2) acidification and overfertilization of forest ecosystems; (3) acidification and fertilization of fresh waters; and (4) coastal eutrophication (Driscoll et al. 2003).

A number of important changes in forest ecosystem function accompany N saturation, including (a) increased nitrification and nitrogen oxide-leaching, with associated acidification of soils and surface waters; (b) depletion of soil nutrient cations and development of plant nutrient imbalances; and (c) forest decline and changes in

species composition (Driscoll, Whitall, Aber, Boyer, Castro, Cronan, Goodale, Groffman, Hopkinson, Lambert, Lawrence and Ollinger 2003). The rate and extent to which these symptoms develop are controlled in part by the capacity of the biota and soils in forest ecosystems to retain deposited N (Aber et al. 1998).

In Biome-BGC, nitrogen (N) availability regulates rates of carbon sequestration under the assumption that N availability limits primary production. In contrast, i-Tree Eco currently does not explicitly consider N. Though the models consider N in a completely separate context, the same biological processes govern nitrogen uptake by plants in both contexts. The addition of a module estimating urban forest nitrogen uptake to i-Tree Eco would be valuable to both scientists and urban landscape managers. Urban forests, particularly those in riparian zones, function as nitrogen sinks (Groffman et al. 2002). In an urban ecosystem with large proportions of impervious surface, the capacity of trees to remove mobile forms of N from the soil solution and sequester it in biomass is a significant ecosystem service. Including a N-uptake estimation component to i-Tree Eco could quantify this service provided by urban trees. In terms of carbon, i-Tree assumes no N limitation in urban areas and uses average tree growth for a region that is adjusted by tree competition and condition, and soon to be adjusted by species.

### **3.1 Module schematics**

Based on the carbon-nitrogen dynamics simulated in Biome-BGC we developed an N module, which could be added to i-Tree Eco. We added an estimate of N held in foliage, but this N is largely returned to the soil each year with leaf senescence. This new N uptake

module produces estimates for leaves, but should also be developed for N in woody biomass to be more comprehensive for total N estimation. The N calculations in Biome-BGC are incorporated primarily to support a more accurate C cycle in which C sequestration is limited by N availability. A schematic of the coupled C and N dynamics in Biome-BGC is shown in Figure 3. The focus of the analysis would be to incorporate information on nitrogen to permit i-Tree to determine if the urban area in question is nitrogen limited and if so, by how much.

Carbon to nitrogen (C:N) ratios have been presented in the literature for litter, soil, and aboveground biomass pools of temperate forest ecosystems. In the natural ecosystems that Biome-BGC was designed to study, nitrogen is often a limiting nutrient, and the amount of nitrogen available dictates how much carbon can be stored in plant tissue. C:N ratios are also key to calculating amounts of nitrogen stored in urban plants.

There are several modeling styles that could be used to estimate N uptake by urban forests. While process models exist that estimate vegetation N, such as TREEDYN3 (Bossel 1996), this approach differs from the i-Tree-Eco allometric method for carbon. As described above, Biome-BGC takes a process modeling approach, in which the N cycle is coupled with the C cycle through established C:N ratios. These ratios could be used in i-Tree -Eco to calculate N storage as a proportion of the C storage, which is already calculated by i-Tree Eco. This is a very simple calculation method.

In this study, we developed a new module in i-Tree Eco, which calculates total leaf N using regression equations developed by Reich et al (2007). The module will utilize equations based upon Global Plant Trait Network (GLOPNET) database, which includes

data collected over 175 sites with 2548 species-site combinations, 2021 different species in total, with 342 species occurring at more than one site (Reich et al. 2007, Wright et al. 2005, Wright et al. 2004). At the different sites, mean annual temperature ranged from -16 to 27.5°C, and mean annual rainfall ranged from 133 to 5300 mm per year.

The GLOPNET dataset was selected because it fits well into the statistical and modular approach taken in the existing i-Tree Eco modules. This methodology will allow users of i-Tree Eco to model foliar N pools ( $N_{mass}$  in  $g/m^2$ ) as a function of phylogeny, growth form (grasses, forbs, shrubs, and trees), leaf habit (deciduous or evergreen), and site specific climate variables including mean annual temperature (MAT), mean annual solar radiation, annual site rainfall, and mean annual vapor pressure deficit (VPD). Future work could include woody biomass, which would give N storage rather than just uptake by leaves through building a database of C:N values for woody tissue in temperate trees.

All leaf-traits in the original GLOPNET database were approximately log-normally distributed across the data set, as were site rainfall and VPD. Therefore, these variables were log-10 transformed for all analyses. Solar radiation and MAT were not changed because their distribution was approximately normal. The N pool held in an individual tree canopy can be calculated by multiplying the N concentration value for that species by the leaf biomass value from i-Tree Eco of the corresponding tree and adjusting it for the tree condition, as shown in Equation 1.

$$Nitrogen (g) = (10^{N_{mass}}) * Leaf Biomass * (1 - \%canopy missing) \quad Eq. 1$$

### 3.2 Carbon release: calculating daily mortality fraction

Biome-BGC simulates plant mortality as a daily fraction of carbon and nitrogen stored in pools related to plant anatomy: leaf, stem, coarse root, and fine root pools. Each plant anatomy pool is divided into sections corresponding to its component proportions of plant tissue types. Biome-BGC includes labile, cellulose, unshielded cellulose, and lignin tissue. After the daily mortality fraction of each plant anatomy pool is calculated, the fraction is divided between plant tissue pools corresponding to the appropriate type of plant anatomy. The mortality fraction is then subtracted from its original living plant anatomy pool. In the case of woody biomes, fire-related mortality is calculated and carbon and nitrogen fluxes transferred between living and litter pools in the same fashion.

Figure 3 shows the mortality process described above in a simplified schematic of carbon cycling in the broader program. Litter pool carbon gradually flows into the decomposition (or microbial) pools, after which carbon dioxide is released back into the atmosphere, in turn to be fixed back into plants during photosynthesis. Fixed carbon is allocated to different plant anatomy pools in proportions dictated by biome-specific ratios, and once again transferred to litter pools as plant mortality takes place.

A prototype i-Tree Eco nitrogen code was developed that provided insight into potential integrations between i-Tree Eco and Biome-BGC and potential obstacles in the way of developing an integration design. i-Tree Eco could use the forest sample to generate initial storage values for some plant anatomy carbon pools used in Biome-BGC's mortality function, but many of the more specific and technical carbon pools could not be filled in by i-Tree Eco. As i-Tree Eco generates carbon pools based on specific tree species and structure rather than more general biome-wide values, i-Tree Eco estimates of carbon

stored in the pools might be more accurate than Biome-BGC's initial estimates of carbon storage. This quandary highlighted the differences between the two programs, but also their potential to supplement each other.

### **3.3 University of Maryland leaf nitrogen estimation**

Leaf nitrogen (N) pool values were calculated for the University of Maryland, College Park, to provide an illustrative example of the method described. Using the field data for 1336 trees from the UMD i-Tree Eco study conducted in 2008 (Keen 1994),  $N_{\text{mass}}$  for each tree was calculated using climate data for 2008, and average foliar nitrogen concentration values from the literature and the GLOPNET database. For species without reported foliar N concentration values, genus averages were used, if present, otherwise the average GLOPNET database value was used.

GLOPNET is a database of foliar characteristics developed by a large group, it includes leaf specific area, leaf mass per unit area, longevity and N concentration in percent among other traits for thousands of species.. Foliar N concentration varies between 1 and 4% of total leaf biomass with most values near 2% common in systems that are neither extremely N limited nor fertilized (Table 2).

The iTree-N module calculated an average value of  $N_{\text{mass}}$  across all the trees of 1.98%. The value is close to the reported values in GLOPNET. Values for species found in this study representing various leaf habit and phylogeny combinations are shown in Table 2. Biome-BGC uses a foliar carbon ratio of 24 for the biome, and assuming a carbon concentration of 47% (McGroddy et al. 2004), then the Biome BGC foliar N concentration is 1.96%. Thus the two measurements are very similar for the UMCP study site.



## 4.0 Discussion

Nitrogen is one of the deterministic nutrients of plant growth, making it important for i-Tree Eco to analyze nitrogen uptake in plants. If the module developed here was integrated into i-Tree Eco, users could improve their understanding of nitrogen requirements and issues of over-supply of nitrogen in their urban ecosystems. Having a leaf nitrogen value would allow users to be better able to understand how urban ecosystems act as nitrogen sinks and possible buffers for the prevention of dead zones in aquatic resources due to a quantitative assessment of their uptake of nitrogen. Although GLOPNET only has data on foliar characteristics, the model also could be extended to include nitrogen in woody biomass, which functions as a longer term sink with much lower variability than in foliar tissue using a database approach with values from the literature.

While the new i-Tree-N module proposed in this paper provides a feasible method of quantifying nitrogen in tree leaves, its capabilities are limited. The model provides estimates of uptake by leaves and not the entire tree. Hence, the value of the module is only a fraction of the actual nitrogen content in the trees. Furthermore, the regression equations used in the model were derived from a database of species all over of the world, and might not be as accurate when used in urban areas. This is because urban trees under N deposition and associated urban environmental conditions might differ from values for trees in 'natural' conditions, especially N limited conditions. The new N module in i-Tree, therefore, serves as the stepping-stone that brings two different ecosystem models together, and would encourage further developments in this area.

Other integrations between i-Tree and Biome-BGC could be useful. The method used by ecosystem models to integrate over time could be accommodated by the i-Tree

model. i-Tree has developed a time-series component that is being tested now and planned for release in a future version, but could potentially gain from investigating the mechanics of the Biome-BGC modeling system. Biome-BGC could be improved with access to the large database of 0.04 ha sampling frames that i-Tree measurements have accumulated over the past decade. i-Tree's database of observations and resulting allometric relationships could provide a means for validation and uncertainty reduction in Biome-BGC (Korol et al. 1991). Improving the ground sampling, increasing understanding of the diversity of tree species types, and obtaining information on carbon and other nutrients currently stored in the environment would help ecosystem models reduce errors currently inherent in the model.

Biome-BGC could be augmented if some aspects from i-Tree were incorporated into the process model. For example, showing how increasing forest cover over a century would improve air quality in a region as the forest leaf biomass increases would be a valuable contribution. Another potential way to improve Biome BGC would be to incorporate more species-specific information, for example, come up with reasonable N uptake based on dominant species and tree size. The species level detail is one of i-Tree Eco's strengths and though that level of detail would be impossible to incorporate into Biome BGC, there are ways to include more specificity to the model.

End users of model output from both i-Tree Eco and Biome-BGC are likely to include organizations that focus on forest management. The Baltimore Washington Partners for Forest Stewardship (BWPFS) is an organization that brings together federal, state and municipal land managers in Maryland to improve forest management and ensure best practices. The original partners, including the Maryland Department of Natural Resources, the Center for Chesapeake Communities, the U.S. Department of Agriculture Beltsville

Agricultural Research Center, the U.S. Fish and Wildlife Service Patuxent Research Refuge, the NASA/Goddard Space Flight Center and the U.S. Army Fort George G. Meade, formed the BWPFS through a Memorandum of Understanding (MOU) in 2006. Collectively, these agencies own and manage over 40 square miles of land, 64% of which is either forested or wetlands.

On June 23, 2011, at a MOU signature ceremony and tree planting event, hosted by the City of Greenbelt, the BWPFS will welcome the City of Greenbelt, the University of Maryland, the U.S. Secret Service, the U.S. Forest Service and the U.S. Geological Survey as new members, expanding the area of contiguous managed landscape to nearly 47 square miles. Through the interaction of Federal land managers with local, state and national organizations in the region, the models presented here can contribute to understanding forest sustainability and the effect of climate on local forest resources by improving the understanding of dynamic relationship between management strategies and forest response.

## **5.0 Conclusions**

Trees have a significant role in mitigating climate change effects. To quantify the benefits of trees accurately it is important that different ecosystem model approaches learn from each other. In this paper, we contrasted two different ecosystem models: i-Tree Eco and Biome-BGC, and based upon this comparison outlined integration designs that would greatly improve both programs. Through the illustrative example of a new nitrogen uptake model in i-Tree Eco, we provide concrete evidence of the benefits of bridging different ecosystem models. We hope that the work brought forth in this paper will inspire

growth among ecosystem models and provide a basis to draft environmental policies in the interest of protecting the ecosystem from impending climate change.

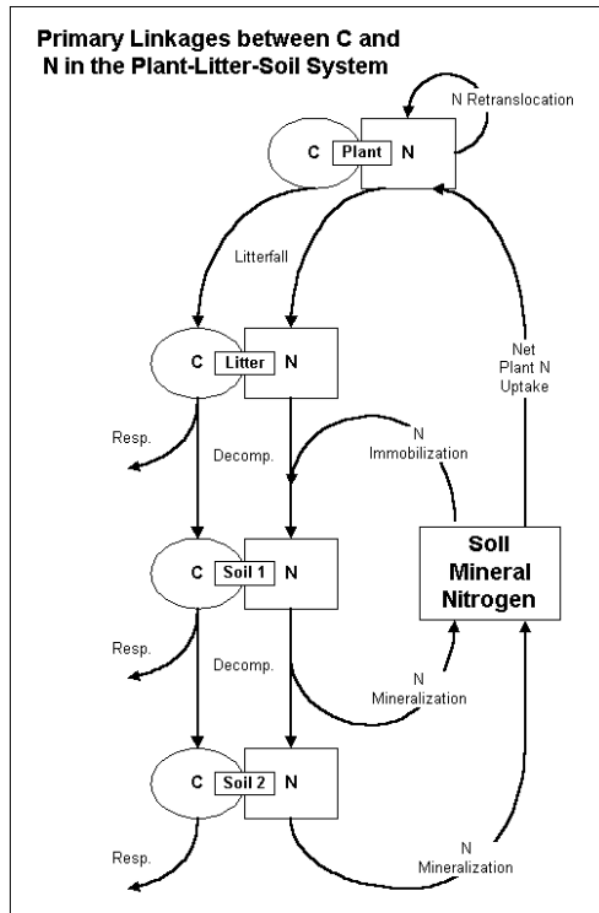
**Table 1.** Strengths and weaknesses of UFORE and Biome-BGC

	I-Tree Eco	Biome-BGC
<b>Strengths</b>	<ul style="list-style-type: none"> <li>• High resolution</li> <li>• Species Specific</li> <li>• User-friendly</li> <li>• Incorporation of local meteorological and pollution data</li> <li>• Applicable to small and large regions</li> </ul>	<ul style="list-style-type: none"> <li>• Applicable to large regions</li> <li>• Simulates development over time</li> <li>• Includes detailed carbon allocation information</li> </ul>
<b>Weaknesses</b>	<ul style="list-style-type: none"> <li>• Labor Intensive field data collection requirements</li> <li>• Error estimation based only on sampling error</li> <li>• Simulates data only for one year</li> <li>• Does not provide carbon allocation information</li> </ul>	<ul style="list-style-type: none"> <li>• Not user friendly</li> <li>• Requires output interpretation</li> <li>• Does not quantify economic value of ecosystem services</li> </ul>

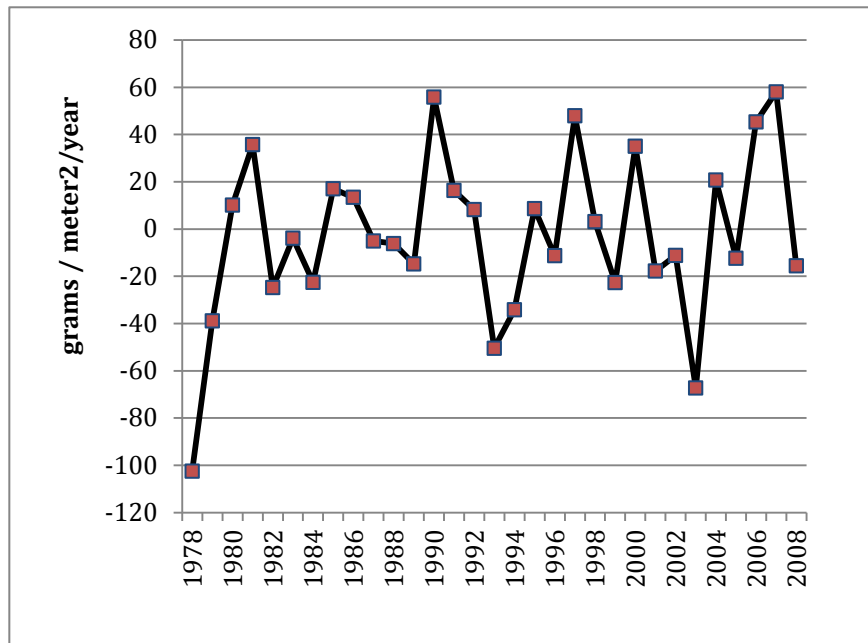
**Table 2:** A set of example data used in the N module of iTree, taken from the GLOPNET database.

Leaf Habit	Phylogeny	Examples	
		Species	N <sub>mass</sub>
Deciduous	Angiosperm	Pyrus pumila	2.32
	Gymnosperm	Prunus sargentii	2.13
Evergreen	Angiosperm	Ilex opaca	2.68
	Gymnosperm	Pinus taeda	3.67

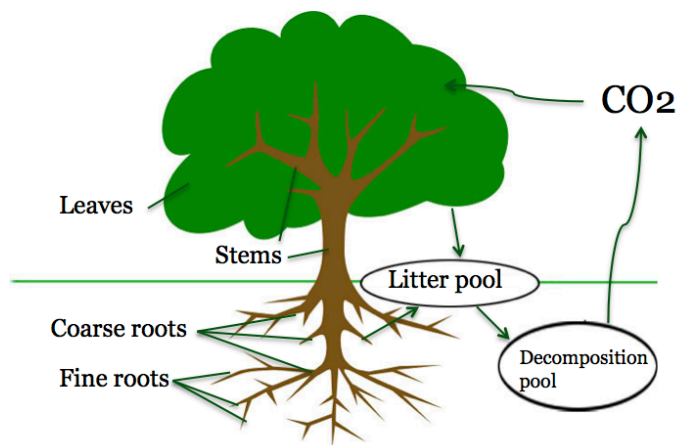
**Figure 1:** Biome-BGC soil processes- Summary of linkages between carbon and nitrogen (White et al 2000)



**Figure 2.** Results showing the annual net biome production from the Biome-BGC run over the University of Maryland College Park system



**Figure 3:** A simplified schematic for carbon cycling in Biome-BGC



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